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Plant Community Diversity After Herbicide Control of Spotted Knapweed

Peter M. Rice
Donald J. Bedunah
Clinton E. Carlson

THE AUTHORS

PETER M. RICE is Research Associate, Division of Biological Sciences, University of Montana, Missoula.

DONALD J. BEDUNAH is Professor of Range Management and Wildlife, School of Forestry, University of Montana, Missoula.

CLINTON E. CARLSON is Research Scientist, Intermountain Research Station, Forestry Sciences Laboratory, Missoula, MT.

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RESEARCH SUMMARY

Herbicides were applied to replicated treatment plots at four sites in west-central Montana with light to moderate spotted knapweed (*Centaurea maculosa* Lam.) infestations. Plant community diversity was determined for two seasons before the herbicide treatments; diversity measurements have been completed for 2 years after the year of spraying. Although knapweed suppression was high, the communities were not converted to grass monocultures. Herbicide-caused depressions in community diversity measurements were small and transitory. Tordon-treated and Curtail-treated plots showed a small 1-year postspray decline. Diversity on those treatments began to increase relative to the untreated plots during the second postspray growing season. Stinger had the least effect on diversity. No large declines in diversity were caused by these herbicide treatments, and the small depressions were probably transitory. Community response data collected from a limited set of pilot study plots suggested that the herbicide treatments had increased diversity by 3 years postspray.

Only small amounts of herbicide were leached below 25 cm. Herbicide residuals in the soil at the 25- to 50-cm depth increment were generally undetectable and did not exceed 26 parts per billion at 30 days, trace after 1 year, and none were detected after 2 years.

Intermountain Research Station
324 25th Street
Ogden, UT 84401

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INTRODUCTION

Spotted knapweed (*Centaurea maculosa* Lam.) has aggressively invaded extensive areas of rangelands and forest sites with open overstories at low to mid elevations in the Northern Rockies (Losensky 1987). The weed had infested more than 7 million acres in Montana and adjoining States and Provinces by 1988 (Lacey 1989). As knapweed increases, cover of more desirable but less competitive grasses and forbs is significantly reduced, sometimes as much as 60 to 90 percent (Baker and others 1979; Bucher 1984; Harris and Cranston 1979). Spotted knapweed causes reduced vigor of native plant populations, less plant diversity on infested sites, and economic losses because of reduced livestock production. It also possibly impacts wildlife populations. Spotted knapweed can expand slowly into natural grassland sites that are undisturbed by human or livestock activities, cause declines in plant community diversity (Forcella and Harvey 1983; Tyser and Key 1988), and invade forested sites disturbed by timber harvesting, thinning, and livestock grazing.

Spotted knapweed is susceptible to low rates of certain herbicides. Picloram, clopyralid, and 2,4-D have high efficacy when applied properly. But biologists and land managers are concerned about the effect of herbicides on nontarget plant species. Will native forbs be eliminated and grass "monocultures" be created by herbicide treatments? What is the response of natural bunchgrass and seral forest communities following herbicide control of spotted knapweed infestations? Our study addresses these practical questions. Preliminary results suggest that herbicides are a feasible vegetation management option for land managers concerned about noxious weed invasions and biological diversity.

METHODS

In Missoula County in west-central Montana, researchers conducted a pilot study to estimate species diversity changes at two sites where herbicides had been applied in 1985 to control spotted knapweed. In 1988 the pilot diversity data were collected—3 years postspray. Those data were then used to plan an indepth formal community response study at four new sites in the same county.

Pilot Diversity Study

The 1988 measurements from the two pilot study sites showed moderate knapweed cover values of 27 and 30 percent. The Fort Missoula site—a bluebunch wheatgrass (*Agropyron spicatum*) series habitat type—had low overall plant diversity in addition to knapweed dominance because of a long history of severe disturbance by livestock and human activities. The Lolo site was dominated by spotted knapweed, but the plant community was much more diverse and representative of a rough fescue (*Festuca scabrella* Torr.) potential natural community. Herbicides had been applied to replicated test plots in the spring of 1985. Picloram (Tordon 22K) and clopyralid (Stinger or Transline) alone at a rate of 0.25 lb acid equivalent (a.e.) per acre were used at both sites, and a mixture of Tordon + Stinger at 0.125 lb a.e. per acre each was applied at the Lolo site. Herbicide treatments and check plots were replicated three times at the Lolo site and twice at Fort Missoula. Livestock grazing was excluded, but not wildlife access. Community response was measured in the 1988 cool season (May and June) using a cover microplot method (Hann and Jensen 1987).

Formal Community Response Study

For the formal community diversity study we chose four sites with low to moderate spotted knapweed infestations, but also still with diverse plant communities. The average spotted knapweed absolute cover for the 1988 warm season was: site 1 (21 percent), site 2 (7 percent), site 3 (10 percent), and site 4 (3 percent). Disturbed sites with 60 to 80 percent spotted knapweed cover are not uncommon in western Montana. Below-average soil moisture and precipitation also limited plant growth during the

1988 growing season. Two sites are grassland habitat types and two are forest habitat types.

Site 1 is a rough fescue/bluebunch wheatgrass (*Festuca scabrella/Agropyron spicatum*) habitat type (h.t.) (Mueggler and Stewart 1980) at 3,200 ft elevation with a northwest aspect. It was used as cattle pasture through the 1950's but since then has been grazed only by wildlife. Site 2 is Idaho fescue/ bluebunch wheatgrass h.t.-western needlegrass phase (*Festuca idahoensis/Agropyron spicatum-Stipa occidentalis*). At 4,200 ft the aspect is south to southwest. Site 2 was grazed by cattle through the 1970's but now is grazed only by wildlife, with significant elk use in winter and spring.

Sites 3 and 4 are adjacently located in a clearcut that was logged and dozer-piled in the mid-1960's. The habitat type (Pfister and others 1977) is ponderosa pine/snowberry (*Pinus ponderosa/ Symphoricarpos albus*), although much of the larger surrounding area is Douglas-fir/snowberry (*Pseudotsuga menziesii/Symphoricarpos albus*). At 4,050 ft elevation, the aspect of site 3 is south to southwest, while site 4 is almost flat. The logging returned sites 3 and 4 to an earlier seral stage, with Richardson's needlegrass (*Stipa richardsonii* Link) and rough fescue (*Festuca scabrella* Torr.) being the most abundant grasses. The location was being grazed by cattle and wildlife. We erected a fence in the summer of 1988 to exclude the cattle but not deer or elk from sites 3 and 4. Deer and elk use on these sites is relatively light.

The soils at sites 1 and 2 are Mollisols. The site 1 soil is a well-drained Typic Argiboroll with a gravelly loam texture. The site 2 soil is a Typic Haploxeroll gravelly loam (Bigarm series). The soil at sites 3 and 4 is an Alfisol—a Typic Eutroboralf silt loam (Greenough series).

Canopy cover and frequency of occurrence by species were determined by cover microplot method (Daubenmire 1959). Each replicated treatment plot (1/20-acre) had five random transects, each transect had five permanently marked microplot locations (10- by 20-inch Daubenmire frames). For each microplot we determined the cover value of every species. Pretreatment plant community data were collected for the 1988 warm season (July-September) and the 1989 cool season (May-June).

Herbicides were applied with a carbon dioxide pressure-regulated backpack research sprayer in 1989 starting after the cool season pretreatment readings for each site. "Early" herbicide treatments were made when spotted knapweed was in the rosette to early bolt stage. "Late" treatments were made when knapweed was in the early to mid-flower stage (table 1). Herbicides were picloram (Tordon 22K) at 0.25-lb active ingredient per acre (a.e. per acre), clopyralid (Stinger or Transline) at 0.25 lb a.e. per acre, and a mixture of 2,4-D at 1 lb a.e. plus clopyralid at 0.19 lb a.e. per acre (Curtail). Each of four sites contained six treatments and an untreated check plot with three randomized blocks or replications.

Table 1—Herbicide application dates

Site	Early treatments	Late treatments
1	5/25/89	7/20/89
2	6/07/89	7/21/89
3	6/21/89	8/08/89
4	6/21/89	8/07/89

Postspray data collection began 1 year after the 1989 herbicide applications. We reread each microplot twice a year—during the cool season (May-June) and again in the warm season (July-August). We have completed the 1990 and 1991 readings and report them here. We will determine community composition through at least 1992.

Plant community data summaries, including average species richness, total number of species, and Shannon-Weaver indices, have been calculated by treatment (Keane and others 1990) through the 1991 warm season. The statistical model is a form of randomized complete blocks with repeated measures in time of the same transect/microplots (Winer 1971).

We determined soil herbicide residues for three depth increments—0 to 5, 5 to 25, and 25 to 50 cm—at 30 days and 1 year after spraying. A fourth increment—50 to 100 cm—was sampled for picloram at 1 year. We also measured picloram residues at 2 years in the 0 to 5 and 5 to 25 cm depth increments. We collected 12 subsamples for each combination of sampling date-site-treatment-depth increment. The like subsamples were mixed to form a composite field sample. The composite samples (two split replicates each) were frozen. The residue analyses were conducted at the Agricultural Experiment Station Analytical Laboratory at Montana State University, Bozeman.

We used quality assurance and quality control (QA/QC) procedures for both the ecological field measurements and the herbicide residue analysis work. We read randomly selected microplots a second time for canopy cover at the end of each sampling period for each site. The second reading was blind; that is, the evaluator did not refer to the data from the first reading. We combined data from the blind microplots to form synthetic transects, then we calculated diversity values. Diversity values for synthetic transect were also calculated from the original readings of the same set of microplots. We quantified the precision of community measurements

Table 2—Community status 3 years postspray on the pilot plots

Treatment	Average percent canopy cover: CENMAC[1]	Other forbs	Grasses	Diversity measurements: Average No. species	Total No. species	S-W index average (1 SD)
			Fort Missoula			
Check plots	27	7	8	16.0	22	0.76(0.035)
Tordon	3	6	28	16.0	22	.94 (.148)
			Lolo			
Check plots	30	20	27	35.3	57	1.13 (.118)
Tordon	3	17	46	34.3	58	1.26 (.167)
Tordon+Stinger	4	16	47	37.7	59	1.29 (.060)
Stinger	16	22	37	37.0	58	1.27 (.050)

[1]CENMAC = *Centaurea maculosa* Lam.

as relative standard deviations for paired original and blind synthetic transects. Soil samples submitted to the residue analysis laboratory included blind split field duplicates and blind herbicide-free check plot soils. The laboratory used internal QA/QC procedures approved by the Environmental Protection Agency. Those methods included analyses of duplicate sample splits, estimating recovery of known additions to herbicide-free check plot soils from the study sites, and incorporation of reagent blanks in the analytic stream.

Table 3—Mean spotted knapweed canopy cover (absolute percentage) during the warm season and average control as a percentage of untreated check plots

	Prespray (1989)	1 year postspray (1990)		2 years postspray (1991)	
	Cover	Cover	Percent reduction	Cover	Percent reduction
Check	10.7	10.1		10.1	
Tordon	9.4	.8	92	1.1	89
Stinger	10.6	.6	94	1.0	90
Curtail	9.6	.9	91	1.6	84

RESULTS AND DISCUSSION

Both the pilot diversity study and the formal community response study suggested that plant diversity could be maintained or even enhanced when these herbicide treatments were used to control spotted knapweed.

Pilot Diversity Study

The two pilot diversity study sites, which had been sprayed in 1985, and the community status measured 3 years later indicated that diversity on the herbicide-treated plots was as high as or higher than on the check plots (table 2). Spotted knapweed control of 87 to 90 percent was still being maintained on the Tordon-treated plots but had declined to 53 percent on the plots that had been sprayed with Stinger alone.

Formal Community Response Study

All six herbicide treatments provided good control of spotted knapweed 1 and 2 years postspray. Little difference occurred between early and late herbicide treatments. The spotted knapweed response to herbicide type is summarized in table 3 by pooling early and late application dates for all four sites. Absolute canopy cover of spotted knapweed in individual treatment plots 1 and 2 years after spraying ranged from less than 0.5 percent to a maximum of 9.2 percent, with all but three of the 72 herbicide-treated plots having less than 3 percent spotted knapweed cover.

We believe that posttreatment year efficacy rates of 99 percent are not realistic for most weed control projects on natural vegetation sites. Weeds will occur where there are skips in the spray swath, droplet-shielded microsites, and resistant individuals. If land managers require more than 99 percent efficacy, they must conduct a followup spot spraying.

Blind QA/QC rereadings indicated excellent precision in determining the community diversity variables. The average relative standard deviation was 5.8 percent for species richness and 5.6 percent for the Shannon-Weaver index (n = 22 rereadings).

The variance among plots receiving the same treatment within a site was usually small, although some outliers occur in the data base (table 4).

The check plot sets generally had the highest average prespray diversity values (tables 5, 6). A graphic inspection of the data for the period 1988 through 1991 shows that, overall, the impact of the

Table 4—Average relative standard deviation and minimum and maximum values calculated from 112 (1988 through 1990 data) replicate treatment sets of three plots

	Relative stand deviation		
	Average	Minimum	Maximum
	---------- *Percent* ---------		
S (Average species richness)	10.2	0	29.3
H' (Shannon-Weaver index)	6.1	.5	26.4

Table 5—Mean Shannon-Weaver diversity index (H' as log base 10) by herbicide for all sites and times of application

	Pretreatment		1 year postspray (1990)		2 years postspray (1991)	
	1988 warm[1]	1989 cool	Cool	Warm	Cool	Warm
Check	1.126	1.365	1.363	1.257	1.345	1.281
Tordon	1.082	1.345	1.262	1.164	1.319	1.253
Stinger	1.077	1.349	1.340	1.240	1.346	1.307
Curtail	1.090	1.344	1.311	1.198	1.341	1.290

[1]In this table warm/cool (season) refers to when the community data were collected: cool = May and June; warm = July and August.

Table 6—Average number of species by herbicide for all sites and times of application

	Pretreatment		1 year postspray (1990)		2 years postspray (1991)	
	1988 warm[1]	1989 cool	Cool	Warm	Cool	Warm
Check	25.6	38.8	40.2	34.8	37.7	33.8
Tordon	24.7	38.4	34.4	28.7	35.8	32.9
Stinger	24.5	39.2	39.0	33.8	38.0	35.0
Curtail	25.8	38.7	37.6	31.5	37.8	34.4

[1]In this table warm/cool (season) refers to when the community data were collected: cool = May and June; warm = July and August.

herbicides on diversity was small and transitory (figs. 1, 2). Tordon-treated plots had the lowest average diversity 1 and 2 years postspray, Curtail was intermediately lower, and Stinger plots were similar to the check plots. The 1-year postspray differences between treatments decreased in the second-year postspray. The measured average number of species and the Shannon-Weaver index were higher for the Stinger and Curtail plots than for the checks by the second-year postspray.

Analytic precision and accuracy of the herbicide residues in the soil samples was good. Recovery of known additions to prespray collected soil blanks from the research sites averaged 88 percent (n = 19). Duplicate analyses of split field samples had an average relative standard deviation of 6.8 percent (n = 32). We detected no herbicides in the reagent blanks (n = 18). The method detection limit (MDL) was 10 parts per billion (ppb). Instrumental responses below MDL are reported as trace.

Herbicide residues in the soil declined rapidly with time and depth (table 7). Although it had the highest surface layer concentrations at day 30 because of its higher initial application, 2,4-D nevertheless degraded most quickly. The maximum concentration of 2,4-D below 25 cm at day 30 was 14 ppb. Only site 1 early treatment still had trace (<10 ppb) detectable 2,4-D below 5 cm after 1 year. As expected,

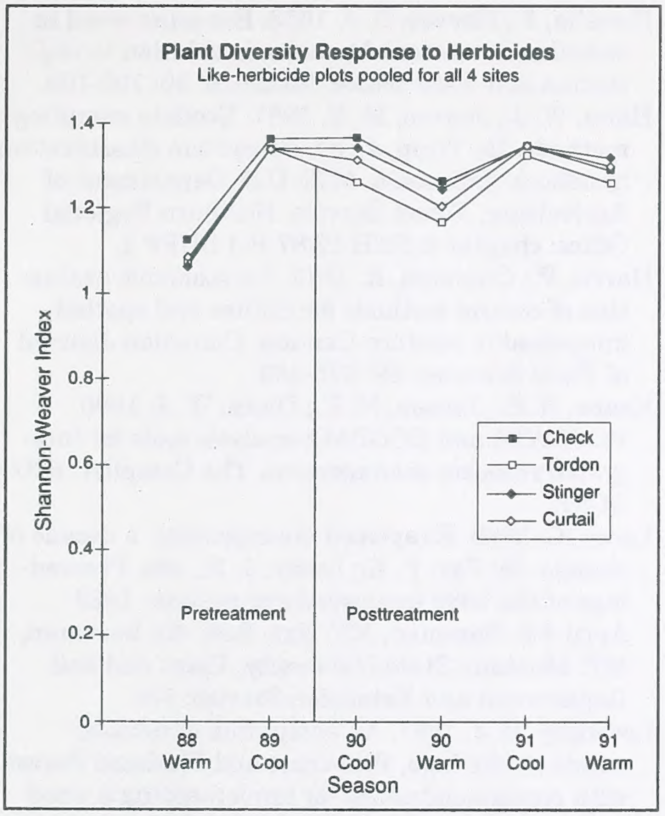

Figure 1—Average Shannon-Weaver diversity index for check plots and herbicide-treated spotted knapweed plots at four sites.

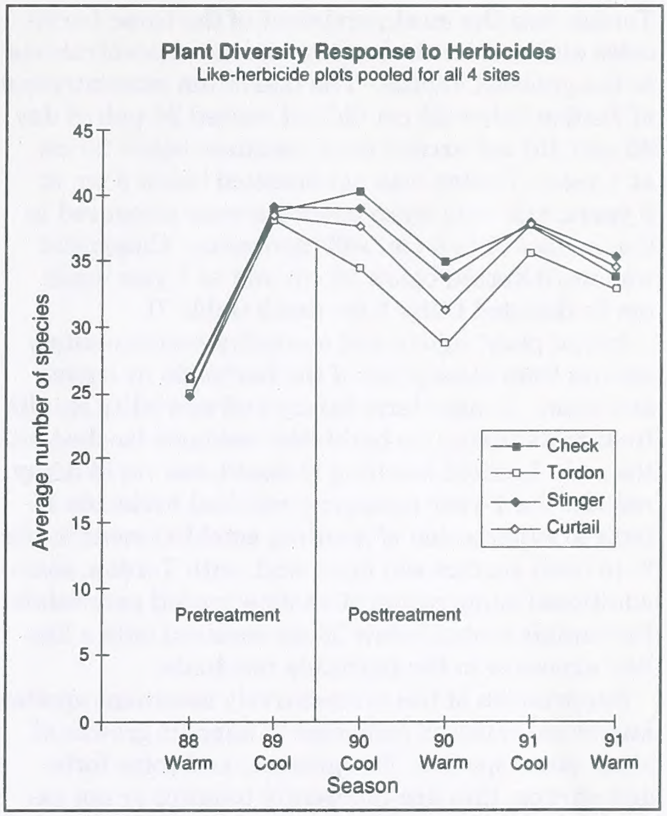

Figure 2—Average number of plant species for check plots and herbicide-treated spotted knapweed plots at four sites.

Table 7—Minimum and maximum soil herbicide residues (ppb-dry weight) pooled for all sites and times of application[1]

	Depth	Curtail 2,4-D + Clopyralid	Stinger Clopyralid	Tordon Picloram
	cm			
Pooled	0 - 5	52 - 535 + 28 - 243	37 - 320	42 - 470
Sites + times	5 - 25	nd - 31 + nd - 11	nd - 14	20 - 270
At 30 days	25 - 50	nd - 14 + nd	nd	10 - 26
(1989)				
Pooled	0 - 5	nd - 26* + nd - 14	nd - 18	14 - 29
Sites + times	5 - 25	nd - t + nd	nd	nd - 16
At 1 year	25 - 50	nd + nd	nd	nd - t
(1990)	50 - 100	ns	ns	nd
Pooled	0 - 5	ns	ns	nd - t
Sites + times	5 - 25	ns	ns	nd
At 2 years				
(1991)				

[1]nd = none detected; t = trace, but less than the method detection limit of 10 ppb; ns = not sampled (residues unlikely); * 2,4-D at 1 year was detected at only one site.

Tordon was the most persistent of the three herbicides and was leached at the highest concentrations to the greatest depths. The maximum concentration of Tordon below 25 cm did not exceed 26 ppb at day 30 and did not exceed trace amounts below 25 cm at 1 year. Tordon was not detected below 5 cm at 2 years, and only trace amounts were measured in the surface (0 to 5 cm) soil increment. Clopyralid was not detected below 25 cm and at 1 year could not be detected below 5 cm depth (table 7).

Initial plant injury and mortality predominately results from absorption of the herbicide by leaves and stem. Longer term injury and mortality results from roots taking up herbicide residuals leached into the soil. Limited leaching to depth and rapid decay restrict the 1-year postspray residual herbicide effects to suppression of seedling establishment in the 0- to 5-cm surface soil layer and, with Tordon, some additional suppression of shallow rooted perennials. Perennials rooted below 25 cm received only a limited exposure to the herbicide residuals.

Suppression of the competitively dominant spotted knapweed releases resources to support growth of other plant species. The grasses, and some forbs and shrubs, that are inherently tolerant or not exposed to this group of herbicides are able to respond during the year of spraying. Herbicide-susceptible forbs and shrubs respond to the limiting resource release in subsequent growing seasons as the herbicide residuals decline. Resistant individuals expand and new plants, including spotted knapweed, establish from various propagules.

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KEYWORDS: *Centaurea maculosa,* leaching, native plants, soil residues

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